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19 Soil Quality in Central Michigan: Rotations with High and Low Diversity of Crops and Manure[1]

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Cover crop, intercrop and manure residues can help protect the soil from erosion, as well as increase organic matter content and water retention, and the efficiency of N use (Karlen et al., 1992). Crop diversity may improve soil quality by increasing the amount, quality and diversity of residues returned to the soil, and by lengthening the time that roots are actively growing in the soil.

Many believe that the robustness of agricultural systems can be improved by imitating natural ecosystems; however, little information has been gathered on crop and residue diversity or its impact on soil quality. Much opportunity exists in Michigan for increasing crop diversity within the traditional corn-based (*Zea mays* L.) system. Knowledge of physical, chemical, and biological measures of soil quality will serve as a base for recommendations and accelerated adoption of increased crop diversity.

APPROACH

Farmers worked cooperatively with researchers to select matched field sites for comparisons of low and high diversity cropping systems. Cropping history, including manure application, was obtained for the 4-yr period prior to soil evaluation. Final site selection for paired comparisons was based on cropping history as well as similarity in topography, aspect, soil type, and distance between paired sites (Table 19–1). A corn field immediately adjacent to the Living Field Laboratory (Kellogg Biological Station, Hickory Corners, MI) was used as a control for the study.

The number of residue sources was determined by considering each crop, cover crop species and manure application. For example, continuous corn for 5

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Table 19–1. Landscape and soil characteristics, and 1989 to 1993 history of cropping and manuring of study sites in south central Michigan.

Comparison	Landscape	Distance between study sites	Soil series	Determined texture	Cropping	Cover crops	Manure	Residue diversity
		~ m	% slope	% gravel-sand silt-clay†			~ Mg ha^{-1}	
Control	Nearly level	40	Kalamazoo sl 0–2%	cl (1-26-44-30)	A A A A C	— — — — —	— — — — —	2
Control	Nearly level		Kalamazoo sl 0–2%	l (15-42-33-25)	A A A A C	— — — — —	— — — — —	2
1 high	S shoulder, small knoll	200	Spinks ls 0–6%	ls (2-86-7-7)	Tr S C S C	— — — — —	— 25 — 25 —	4
1 low	S shoulder, small knoll		Spinks ls 0–6%	ls (2-87-7-6)	C C C C C	— — — — —	25 25 — — —	2
2 high	Nearly level bottom	200	Capac l 0–3%	cl (1-40-24-35)	C C S W C	cl — — cl cl	— — — — —	4
2 low	Nearly level bottom		Capac l 0–3%	scl (1-53-18-29)	C C C C C	— — — — —	25 25 25 25 25	2
3 high	Nearly level	100	Capac l 0–3%	scl (16-49-21-29)	C C S W C	cl — — cl cl	— — — — —	4
3 low	Nearly level		Capac l 0–3%	scl (4-51-23-36)	C S W C C	— — — — —	— — — — —	3
4 high	Rolling, midslope	100	Marlette fsl 2–6%	sl (10-67-23-10)	C S C S C	cl — — — —	— — 25 — —	4
4 low	Rolling, midslope		Marlette fsl 2–6%	sl (6-66-24-11)	C C C C C	— — — — —	25 25 25 25 25	2
5 high	Nearly level	1000	Capac l 0–3%	scl (3-45-27-28)	C S W C C	— — cl cl cl	— — — — —	4
5 low	Nearly level		Capac l 0–3%	scl (3-53-25-22)	A A A C C	— — — — —	25 25 25 25 —	3
6 high	Small undulations	150	Ithaca l 0–3%	scl (8-46-22-31)	Cu W C S C	— — — — —	— — — 25 —	5
6 low	Small undulations		Ithaca l 0–3%	scl (1-52-21-27)	C C S C C	— — — — —	— — — — —	2
7 high	Nearly level	2000	Kalamazoo sl 0–2%	sl (1-58-25-17)	C C W C C	— — cl — —	25 — 25 — —	4
7 low	Small undulations		Kalamazoo sl 2–6%	sl (6-56-26-18)	C C C C C	— — — — —	— — — — —	1
8 high	Small undulations	100	Capac l 0–3%	cl (6-39-33-29)	C B Cu W C	— — — cl —	25 25 25 — —	6
8 low	Small undulations		Capac l 0–3%	sl (6-54-28-18)	C C C C C	— — — — —	25 25 25 — —	2
9 high	S shoulder, small knoll	4000	Marlette fsl 2–6%	sl (17-64-20-16)	A W C S C	og — v — v	— 12.5 — — —	7
9 low	S shoulder, small knoll		Marlette fsl 2–6%	sl (10-58-23-19)	W F C S C	— — cl — —	— — — — —	4

† Bulked samples, sand + silt + clay = 100%. C = Corn, S = Soybeans, A = Alfalfa, W = Wheat, Tr - Triticale, Cu = cucumbers, F = Fallow, cl = clover, og = orchard grass, v = vetch. Manure was generally from on-farm dairy or hog operations, and it was assumed that the type applied did not change from year to year. Capac: fine-loamy, mixed, mesic Aeric Ochraqualfs. Ithaca: fine, mixed, mesic, Glossaquic Hapludalfs. Kalamazoo: fine-loamy, mixed, mesic Typic Hapludalfs. Marlette: fine-loamy, mixed, mesic Haplic Glossudalfs. Spinks: sandy, mixed, mesic Psammentic Hapludalfs.

yr with no cover crops or manure was counted as one source; whereas, a rotation that included corn, wheat (*Triticum aestivum* L.), and soybeans [*Glycine max* (L.) Merr.], clover as a cover crop, and manure applied every other year counted as five. Selection of a pair of fields for comparison required that the pair have a minimum difference of two residue sources. Of the field pairs selected, it was later determined that two (Pairs 2 and 5) did not differ by two residue sources because farm records and/or farmer recollection were incorrect.

Each field plot was approximately 0.01 ha in size. Six sampling stations were established in each field plot in nontrafficked interrows of corn having few obvious disturbances such as fertilizer bands. Soil properties evaluated at the 0- to 20-m depth included bulk density; percentage of gravel (>2mm); particle-size analysis by the hydrometer method; water holding capacity (30 kPa to 1.5 MPa); penetrometer resistance (n = 6 per station); A-horizon and rooting depth (n = 2 per station); infiltration rate (time required for 2.5 cm of water to infiltrate); inorganic N (NO_3^+ + NO_2^- + NH_4^+) by colorimetry; pH; mineralizable N by anaerobic incubation; total C by high temperature combustion; total N by the Kjeldahl procedure; extractable P by the Bray method and soil respiration and microbial biomass. Infiltration and respiration measurements were made in the early morning and in early afternoon approximately 4 to 6 h after the first irrigation. In-field soil quality measurements were conducted using the methods described by Sarrantonio et al. (1996, this publication). Corn yield was determined by harvesting four, 6.8-m rows within each plot.

A paired comparison t-test was used to test differences in soil properties within a field pair and across the nine pairs. Differences in soil properties between rotations with high and low residue diversity were tested by two-way ANOVA using a procedure that treated sampling station values as replicates. Three field pairs that differed greatly in the number of years manure was applied were considered separately. Infiltration data were transformed to the $\log_{10}$ and microbial biomass C to the square-root form in order to obtain a normal distribution for analysis.

Soil quality is typically assessed by measuring a number of soil and crop properties. In our study, 21 different properties were measured on each field. Currently, there is not a specific threshold value assigned to each property that separates a higher quality soil from a lower quality soil. It is likely that such threshold values would, at a minimum, be soil specific. In addition, it is likely that a single soil could have some measured properties that indicate a higher soil quality while having other measured properties that indicate lower soil quality. For example, soil A, as compared with soil B, could have higher yield and soil respiration as indicators of higher soil quality but higher penetration resistance and lower water holding capacity. Therefore, to facilitate our discussion, we assumed that the following characteristics were associated with higher soil quality:

- corn yield was higher or rooting was deeper,
- topsoil was deeper or had a lower bulk density or resistance to penetration,
- topsoil had a higher water holding capacity or faster infiltration,
- topsoil had a higher concentration of total C, total N or mineralizable N but lower extractable N or P,

- topsoil had a lower ratio of C to N,
- topsoil had a higher ratio of mineralizable N to total C,
- topsoil had a higher microbial biomass, or higher microbial respiration rate (but lower specific respiratory activity),
- topsoil had a higher ratio of microbial biomass to total C, or higher soil respiration rate.

RESULTS AND DISCUSSION

Soils among all field pairs were of medium texture and bulk density, slightly acid to neutral and fertile (Table 19–2). Few patterns could be discerned from comparisons of <individual> low and high-diversity pairs; however, improved soil quality, as indicated by enhanced soil property values, tended to be associated with high residue diversity plots. For example, of 63 significant differences in soil properties (excluding pH) that occurred in the nine comparisons, 38 were in the direction of improved soil quality in the high diversity plots versus 25 in the low diversity plots. And in a majority of comparisons (Pairs 2, 3, 4, 6, 7, and 9) a higher number of significant differences occurred in the high diversity plots than the low diversity plots.

High and variable concentrations of extractable N in some plots (Pairs 1, 3, and 5) may have been due to sampling near fertilizer bands. The high concentrations of extractable P were generally associated with long-term manuring (Pairs 1, 4, 7, and 8). Later interviews with farmers indicated that at three locations (Pairs 2, 4, and 5), the low diversity plots had, in fact, received yearly applications of manure during the 5-yr study period. Similar variability in soil properties of the control plots also was observed.

Combining results from all nine comparisons showed that corn yield and total and mineralizable N were higher in fields receiving a higher diversity of residues (Table 19–3). The variation between high and low residue diversity plots was 25% or less as indicated by the ratios. Among the 22 soil properties evaluated, 9 differed by <5% among high and low diversity plots. But all 13 soil properties showing an increase of 5% or greater in the direction of improved soil quality occurred in the high diversity plots.

For paired low and high diversity plots having similar manure histories (Pairs 1, 3, 6, 7, 8, and 9), significant improvement occurred in resistance to penetration, total and mineralizable N, soil respiration after irrigation, and ratio of mineralizable N to total C (Table 19–3). But in addition, 14 of 16 improvements of 5% or greater in soil quality properties were in the high diversity plots. Increased extractable N and P were the two soil properties that showed an increase of 5% or greater in the low diversity plots. Variation between these high and low diversity plots receiving similar manuring was as high as 57%.

For the comparisons with dissimilar manuring (Pairs 2, 4, and 5), where manure was applied much more frequently to the low diversity than the high diversity plots, soil fertility was similar among pairs except for extractable phosphorus (Table 19–3). Moreover, of 16 improvements of 5% or greater in soil

Table 19–2. Paired comparisons of soil physical, chemical, and biological properties in corn fields with high or low diversity of residues returned to the soil during 1989–1993. Values are means (n = 6) for the 0- to 20-cm soil layer unless noted otherwise.

Comparison	Residue diversity	pH	Bulk density	Penetration resistance	Water holding capacity	Topsoil depth	Corn rooting depth	Infiltration rate: Initial†	Infiltration rate: After irrigation§	Corn yield¶	Total C	Total N
			g cm^{-3}	kg cm^{-2}	cm	cm	cm	cm min^{-1}	cm min^{-1}	Mg ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
Control	Low	5.2	1.05	0.9	1.90#	nd	24.8	3.7††	0.4	nd††#	29.1	2.84**
Control	Low	5.4	1.25**	1.0	1.25	nd	25.8	0.2	0.9	nd††#	26.1	2.46
1	High	6.5#	1.38	wet nd	0.98	25.9	23.3	0.4	0.4	5.56	19.3	1.33
1	Low	5.8	1.43#	wet nd	1.02	28.5#	23.3	0.4	0.3	7.35#	21.7	1.73*
2	High	6.9	1.01	0.89	2.29	26.3	21.8	23.2	9.4	10.8*	48.4	6.01
2	Low	7.1*	1.03	0.46	1.69	31.4*	22.0	11.4	7.2	8.9	45.5	4.62
3	High	6.3	1.06	0.67	1.20	30.0	24.8	17.5*	3.4*	11.1**	34.2	3.66
3	Low	6.5	1.29*	2.40*	1.34	29.8	22.6	0.6	0.1	5.84	35.3	3.43
4	High	5.9	1.26	1.86	2.48	25.1	19.7	1.7	0.9	10.7	34.4#	2.86
4	Low	5.7	1.25	1.06	2.20	22.8	22.8#	3.7	1.7	10.1	27.9	2.58
5	High	6.4	1.15	1.88	1.52	28.6	23.2	7.8	3.0	11.1*	31.7	2.96
5	Low	6.3	1.29	1.84	1.51	28.1	25.4**	12.2	7.4	6.48	36.2	3.67*
6	High	6.1	1.25	0.36	1.10	25.3	25.1	1.0	0.3	10.3	32.7	3.61
6	Low	5.8	1.23	0.83**	1.49*	23.8	23.8	1.3	0.3	9.74	34.4	3.20
7	High	5.6	1.44	0.93	1.99*	29.8*	27.8**	0.3	0.1	8.23	35.3**	3.36**
7	Low	6.1	1.40	1.48	1.38	26.7	21.8	0.3	0.1	7.15	21.2	2.11
8	High	5.8	1.29**	1.08*	1.72	26.1	22.6	0.9	0.1	10.3	38.2	3.49
8	Low	6.8	1.15	0.59	2.36#	24.4	20.9	3.3	0.2	10.7	34.4	3.23
9	High	5.8	1.27	1.03	2.18*	21.6	20.1	1.8	0.3	5.48	21.2	2.09
9	Low	5.9	1.20	0.72	1.00	23.9**	23.3**	1.2	0.4	8.22*	21.2	2.10

(continued on next page)

Table 19–2. Continued.

Comparison	Residue diversity	Extractable N	Mineralizable N	Extractable P	Microbial biomass C	Soil respiration initial	Soil respiration after irrigation	Microbial respiration	Specific respiratory activity	Mineralizable N/ total C	C/N	C_{mic}/ Ctitak
		kg ha^{-1}				kg CO_2-C		$ha^{-1}d^{-1}$	††	$mgNg^{-1}C$	w/w	%
Control	Low	46.9	28.9	108	935	40.9	24.7	16.9	18.0	0.99	10.3	3.22
Control	Low	44.5	29.2	119	947	33.4	18.6	22.9	24.6	1.12	10.6	3.72
1	High	29.1	14.4#	506#	720	17.2	10.8	23.9	36.1	0.75#	14.7	3.77
1	Low	191*	3.30	436	811	17.3	8.83	33.1**	50.2	0.15	12.6	3.81
2	High	50.0*	36.6	157	1338	23.8	10.6	21.7*	16.9#	0.74#	8.4	2.77
2	Low	36.9	30.1	118	1153	30.4	15.8#	8.90	7.77	0.67	9.9*	2.58
3	High	243#	27.0	92.2*	1054	42.4	18.0	11.4	10.5	0.79	9.4	3.17**
3	Low	14.3	27.4	77.1	974	29.7	13.9	10.3	10.6	0.78	10.3*	2.79
4	High	24.6	40.0	252	749	32.8	10.5	5.87	7.37	1.23	11.9	2.37
4	Low	29.6	48.6	990**	877	27.9	6.68	9.75	10.9#	1.71	10.8	3.15
5	High	39.4	19.0	120	1081	22.2	3.08	13.4	11.8	0.60	10.8	3.42
5	Low	207	30.7	119	1133	34.8	32.4**	13.2	12.0	0.84	9.9	3.16
6	High	63.5	24.0	176*	664	39.9	6.21	9.50	18.0	0.75	9.1	2.02
6	Low	52.0	18.8	126	617	60.3#	6.86	9.17	15.5	0.56	10.7**	1.85
7	High	29.9	49.9*	567*	909**	27.7	29.6*	22.7	24.8	1.44	10.5	2.58
7	Low	22.8	30.1	135	567	31.1	15.0	10.2	19.1	1.43	10.0	2.69
8	High	81.4#	26.2	170	848	37.1	15.4	13.8	16.0	0.68	10.9	2.23
8	Low	31.5	25.8	355**	1000†	27.1	11.4	16.4	16.8	0.75	10.7	2.93†
9	High	28.7	29.0**	58.8	757†	6.42	12.5	7.96	10.7	1.39**	10.1	3.31
9	Low	94.9*	18.3	171**	579	45.7	11.0	5.36	9.67	0.87	10.1	2.80

†,*,** Significant at the 0.1, 0.05, and 0.01 levels, respectively (symbols arbitrarily placed on larger value); nd = not determined.
‡ Falling head, 2.5 cm H2O.
§ 4–6 h after initial irrigation.
¶ $n = 4$.
# yield averaged 8.53 Mg/ha at adjacent experimental field trials under the same management.
†† mg CO_2–C g^{-1} Cmic d^{-1}.

Table 19–3. Comparison of soil properties in corn-based rotations with high or low diversity of residues returned to the soil, analyzed by two-way ANOVA procedures using subsamples as replicates.

	All nine comparisons			Similar manuring Comparisons 1,3,6,7,8,9			Dissimilar manuring Comparisons 2,4,5		
Soil property	High diversity	Low diversity	Ratio	High diversity	Low diversity	Ratio	High diversity	Low diversity	Ratio
Bulk density, g cm^{-3}	1.24	1.25	0.99	1.28	1.28	1.00	1.14	1.19	0.96
Penetration resistance, kg cm^{-2}	0.97	1.04	0.93	0.68	1.00*	0.68	1.54†	1.12	1.38
Corn rooting depth, cm	23.1	22.9	1.01	23.9†	22.6	1.06	21.5	23.4*	0.92
Topsoil depth, cm	26.5	26.6	1.00	26.4	26.2	1.01	26.7	27.4	0.97
Water holding capacity, cm	1.72	1.54	1.12	1.53	1.41	1.09	2.10	1.80	1.17
Infiltration rate, cm min^{-1}	2.21	1.77	1.25	1.26	0.84	1.50	6.81	7.98	0.85
Infiltration rate after irrigation, cm min^{-1}	0.68	0.58	1.17	0.33	0.21	1.57	2.94	4.47	0.66
pH	6.0	6.0	1.00	5.9	6.0	0.98	6.2	6.1	1.02
Total C, Mg ha^{-1}	32.8†	30.9	1.06	30.2†	28.0	1.08	38.2	36.5	1.05
Total N, Mg ha^{-1}	3.27*	2.96	1.10	2.92**	2.63	1.11	3.95	3.62	1.09
C:N ratio	10.6	10.6	1.00	10.8	10.7	1.01	10.4	10.2	1.02
Extractable N, kg ha^{-1}	65.5	75.5	0.87	79.2	67.7	1.17	38.0	91.1	0.42
Mineralizable N, kg ha^{-1}	29.6*	25.9	1.14	28.5***	20.7	1.38	31.9	36.4	0.87
Extractable P, kg ha^{-1}	233	281	0.83	262	217	1.21	177	409**	0.43
Soil respiration, kg C ha^{-1} d^{-1}	34.8	33.5	1.04	38.0	34.7	1.10	27.8	31.0	0.90
Soil respiration after irrigation	13.2	13.6	0.97	15.5*	11.0	1.41	8.22	18.3**	0.45
Microbial biomass C, kg ha^{-1}	900	855	1.05	822	758	1.08	1060	1050	1.01
Microbial respiration, kg C ha^{-1} d^{-1}	14.5	12.9	1.12	14.9	14.1	1.06	13.7	10.4	1.32
Specific microbial respiration, mg g^{-1} d^{-1}	16.9	16.8	1.01	19.4	20.4	0.95	12.0	10.1	1.19
$C_{microbial}/C_{total}$, %	2.87	2.86	1.00	2.88	2.81	1.02	2.86	2.94	0.97
Mineralizable N/C_{total} mg^{-1} g^{-1}	0.93	0.87	1.07	0.97**	0.77	1.26	0.86	1.06	0.81
Corn yield, Mg ha^{-1}	9.29*	8.28	1.12	8.51	8.17	1.04	10.9*	8.51	1.28

†,*,**,*** Significantly different at the 0.1, 0.05, 0.01, and 0.001 levels, respectively (symbols arbitrarily placed on larger value).

properties, 9 were in the direction of improved soil quality in the low diversity plots vs. 7 in the high diversity plots. This suggests that prolonged manuring, as evidenced by high extractable phosphorus, may be detrimental to economic yields. But higher residue diversity seemed to counteract the adverse effects of prolonged manuring. Variation between high and low diversity plots receiving dissimilar manuring was as high as 68%.

Water infiltration rates and soil respiration were lower for all plots after irrigation as compared to preirrigation (Table 19–2). The postirrigation assessment serves as a measure of the soil's response to near-optimal conditions of moisture and aeration; however, the 4- to 6-h drainage period between infiltration measurements was not adequate to allow for the soil to fully drain to field capacity. Thus, water-filled pore space exceeded 60% and, as discussed by Parkin et al. (1996, this publication), CO_2 diffusion rates were markedly reduced.

These results suggest that increased diversity of residues was associated with an improvement in soil quality which was expressed as improved soil tilth, nutritional status, and biological activity. The increase in total, but not extractable or mineralizable N suggests that the improvement in nutritional status resulted from an increase in the pool of organic N in the soil. Results presented here are consistent with those of Reganold et al. (1993).

Indices of cropping diversity and manuring frequency also were devised and correlated with soil properties (e.g., microbial biomass C, r = 0.57). This assessment revealed that improvements in soil quality could not be associated simply with diversity in rotations, cover crops or manure applications, but rather with diversity and frequency in all three sources of residue.

Although factors such as quantity and quality of residues could not be controlled, the cropping histories do not suggest that these factors bias the results. It is likely that replacing corn with either wheat or soybeans would result in lower quantities, and equal or slightly higher quality, of residues returned to the soil. Thus, results reported here indicate that a higher diversity of C inputs from crop residues can lead to improved soil quality after a single rotation cycle.

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